

# Challenges in industrial point sensing- NDIR



**John Saffell**

Technical Director

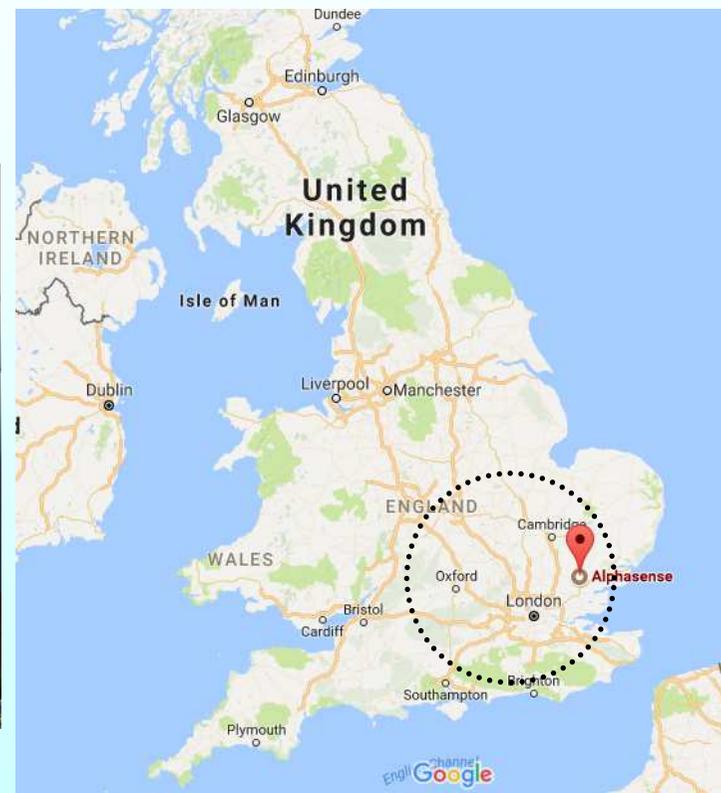
Alphasense Ltd.

Great Notley, ESSEX

[jrs@alphasense.com](mailto:jrs@alphasense.com)

# Alphasense

- A private company in the UK, located near Stansted airport, between London and Cambridge
- Established January 1997
- **We manufacture gas sensors**



- **Market:** Industrial safety & air quality sensors
- **Research investment:** >£2M/ annum
- **Staff:** 75+

# Our Technologies



**Electrochems**



**MOXs**



**NDIRs**



**Pellistors**



**PIDs**



**OPCs**

# Beer Lambert Law (II)

In 1852, Beer showed that the absorption coefficient for monochromatic light is proportional to the concentration of the absorber and thus led to the Beer Lambert Law:

$$\log(I/ I_0) = - \epsilon c l$$

where:

$I_0$  is the incident light power

$c$  is the molar gas concentration

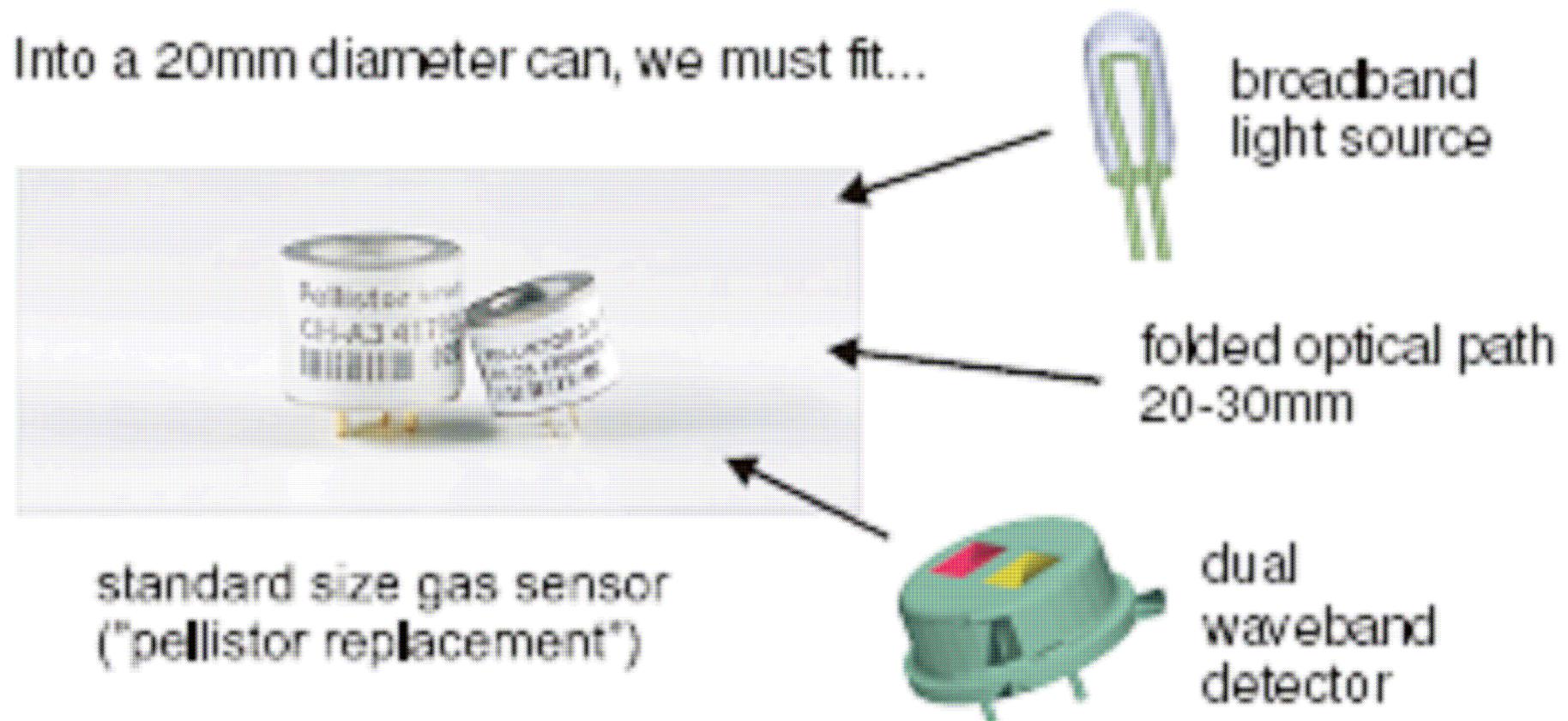
$l$  is the pathlength and

$\epsilon$  is the molar absorption coefficient

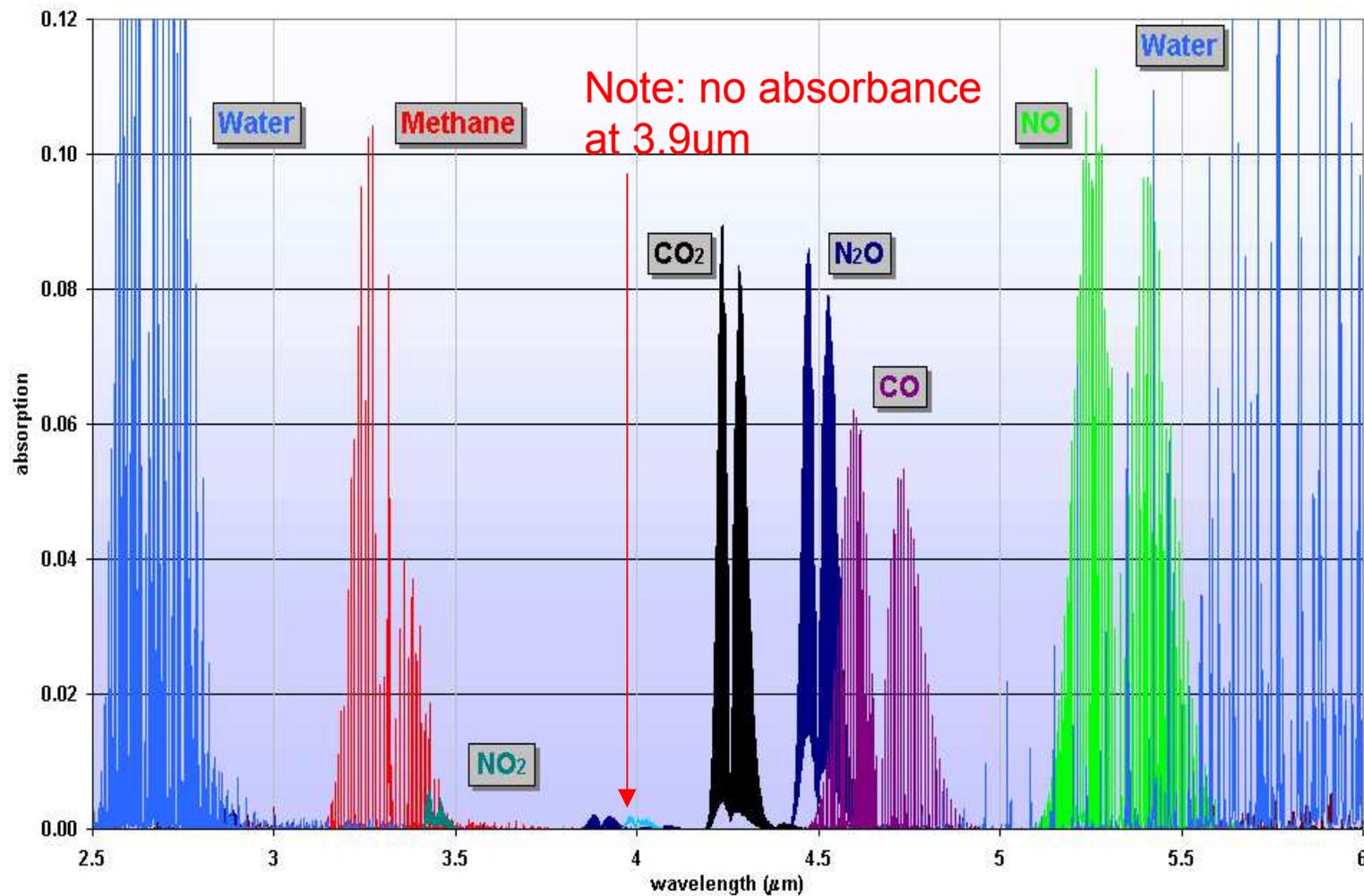
# How does NDIR work?

Non-Dispersive Infrared detection integrates the Beer-Lambert Law over a band of wavelengths.

**The trick is to fit it into a small sensor.**



# Many gases have absorption bands in the mid-IR



# What gases to measure?

## **Methane, hydrocarbons**

Safety (0-5%, 0-100%)

Leaks (0-500 ppm)

## **CO<sub>2</sub>**

IAQ/ ventilation control (0-2000 ppm)

Safety (0-5%)

Combustion control (0-18%)

Process control- intensive growing, bioreactors (0-100%)

**Methane and CO<sub>2</sub> are the two most important greenhouse gases (GHGs)**

## **Others**

Ammonia -agricultural, refrigeration (0-100 ppm)

Aromatics -health and safety (0-5 ppm)

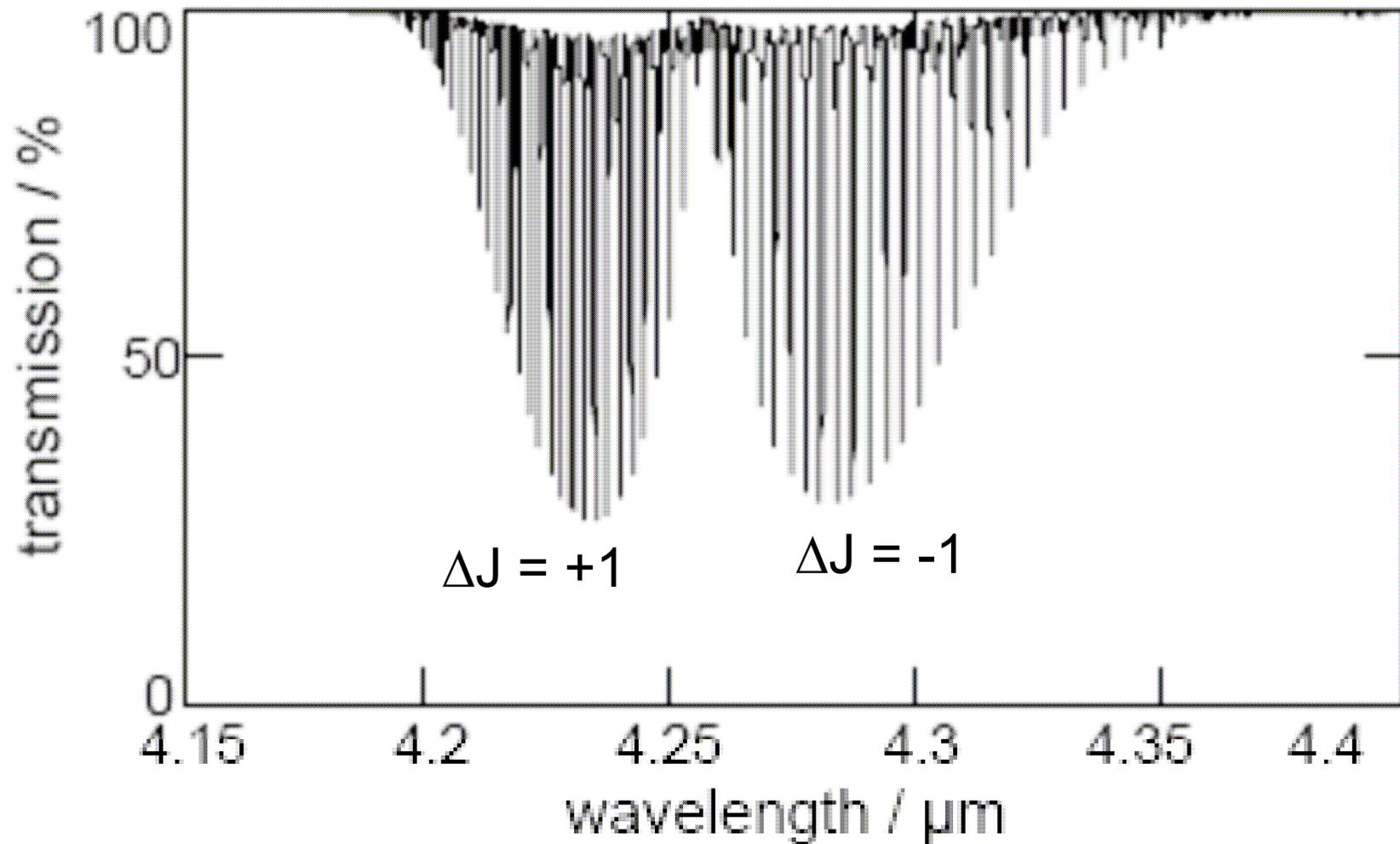
Water -semiconductor processing (0-100 ppm)

## Applying the Beer Lambert Law to CO<sub>2</sub>

- We want to measure the CO<sub>2</sub> band between 4.2 and 4.4 micrometers.
- We require a reference channel at 3.9 micrometers to correct for source and detector drift, and temperature dependence.

What shape is the CO<sub>2</sub> band?

Carbon dioxide absorption, calculated from HITRAN with 32 mm pathlength at 0.1% CO<sub>2</sub> concentration



We now have a summation of Beer-Lambert Law for each line in the absorption band:

$$I = \sum I_0 e^{-\epsilon c l} \Big|_{\lambda}$$

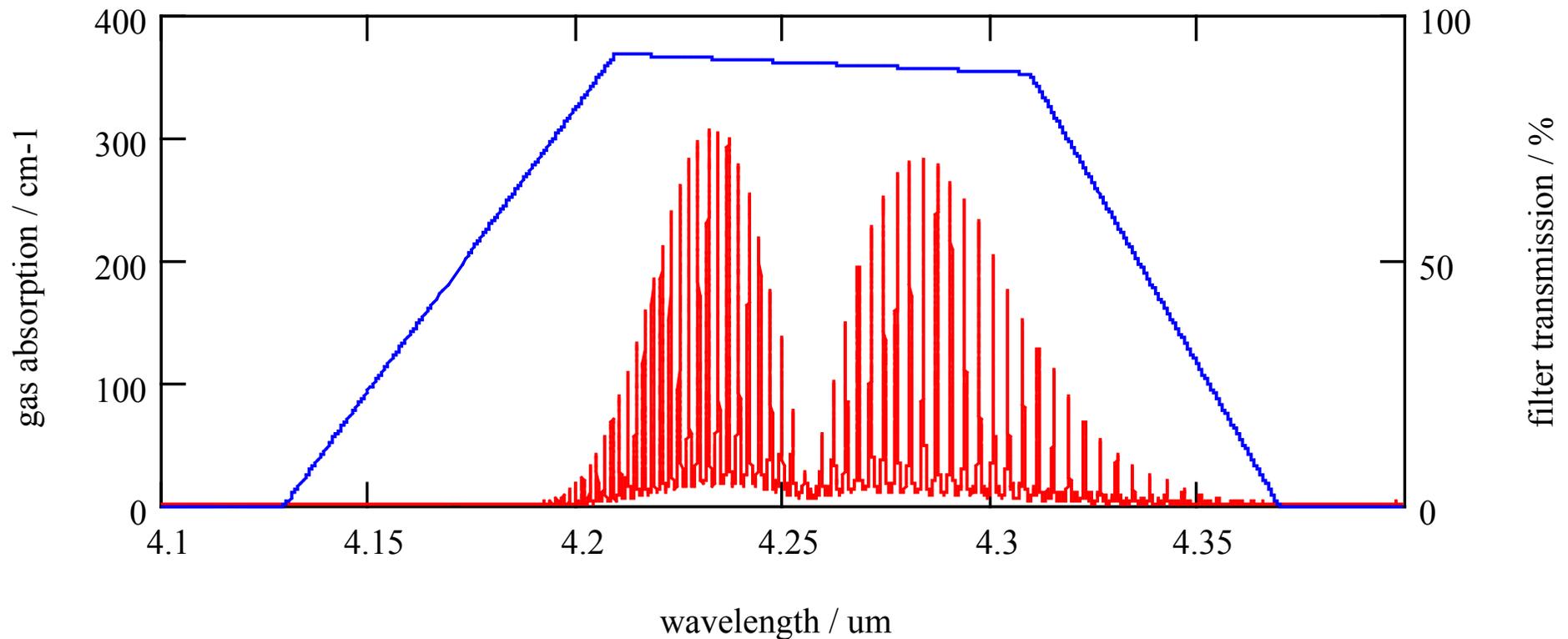
$\epsilon$  is not a constant, it varies for each peak in the band

Let us now look at the choice of filter.

# Filter selection is critical to minimise non-Beer Lambert performance

- Most NDIR gas sensors use either pyroelectric or thermopile dual detectors. Single low cost detectors save cost; and more expensive but better performance photovoltaic or photoconductive detectors are available, with much better  $D^*$ , but at much greater cost.
- Manufacturers of NDIR detectors obtain filters from different suppliers with different performance.  
**Caveat Emptor.**

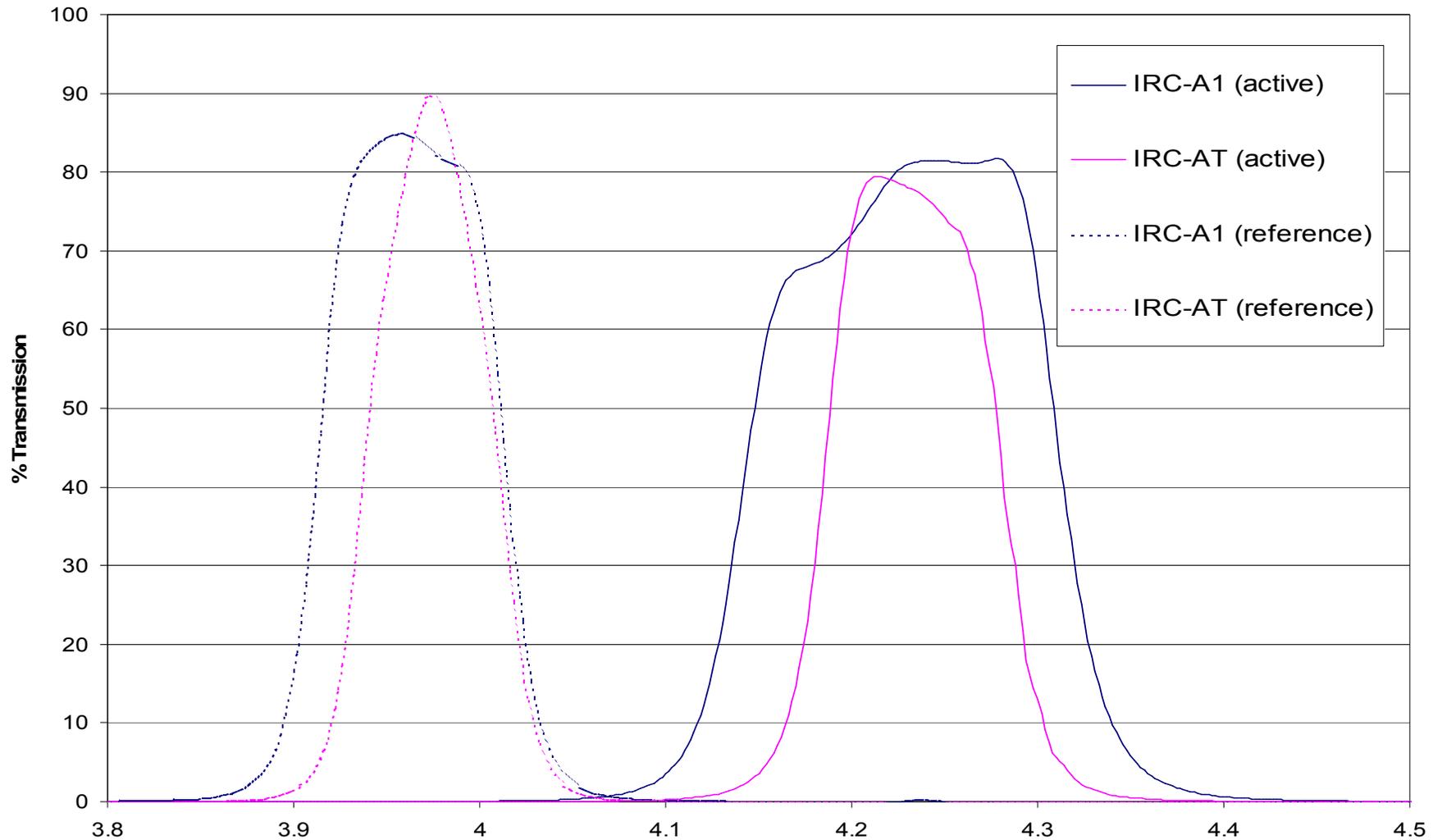
Ideally, the detector filter should match the absorption band-  
this is difficult over the entire temperature range  
and incident angle onto the filter.



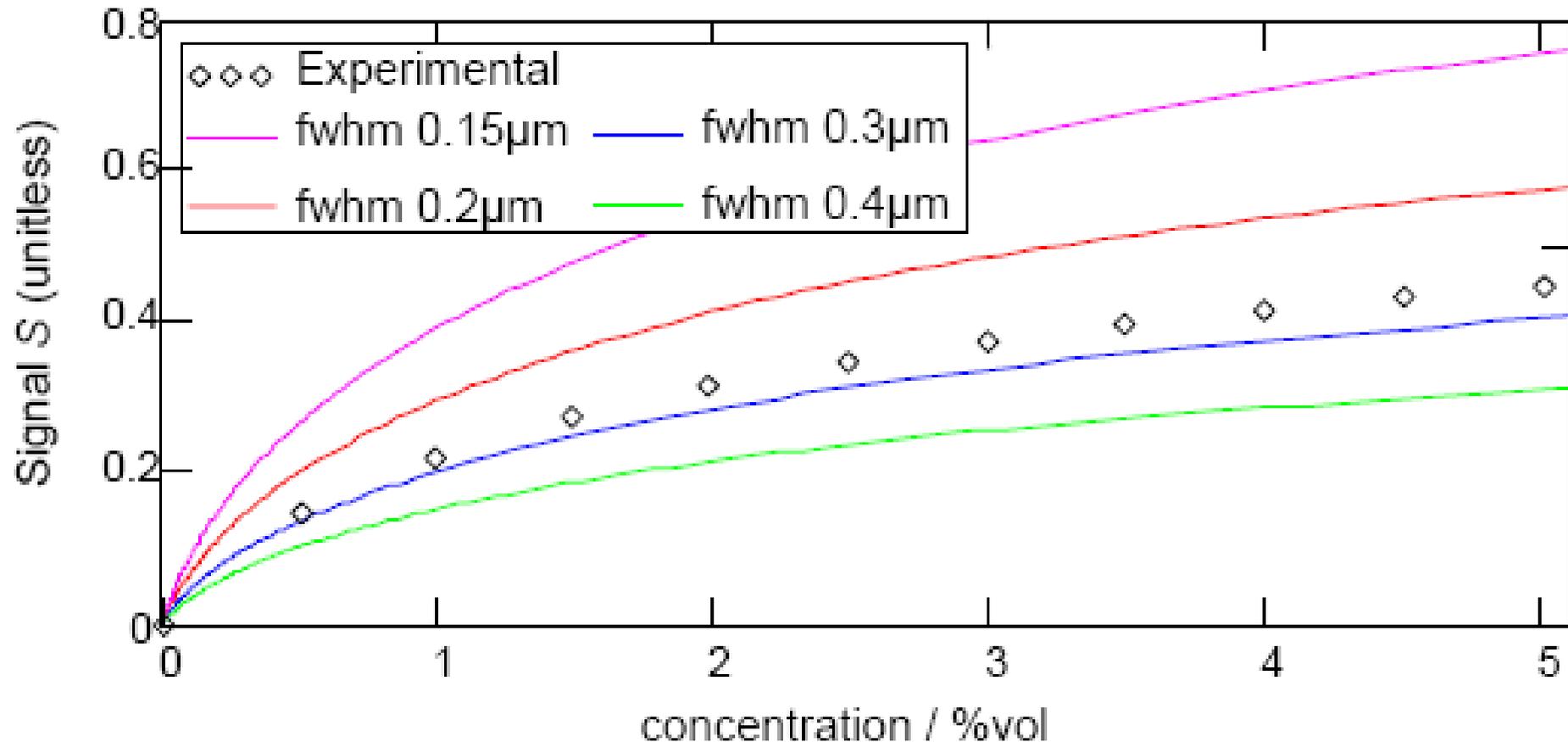
# Choosing the right filter- IR notch filters are not ideal:

- Filter bandwidth should match the absorbance band.
- Filter centre frequency should be in the middle of the absorbance band.
- “Top hat” performance is a goal.
- Non 90° incident rays should not see a shifted filter wavelength.
- Temperature shift of the filter should be minimised.

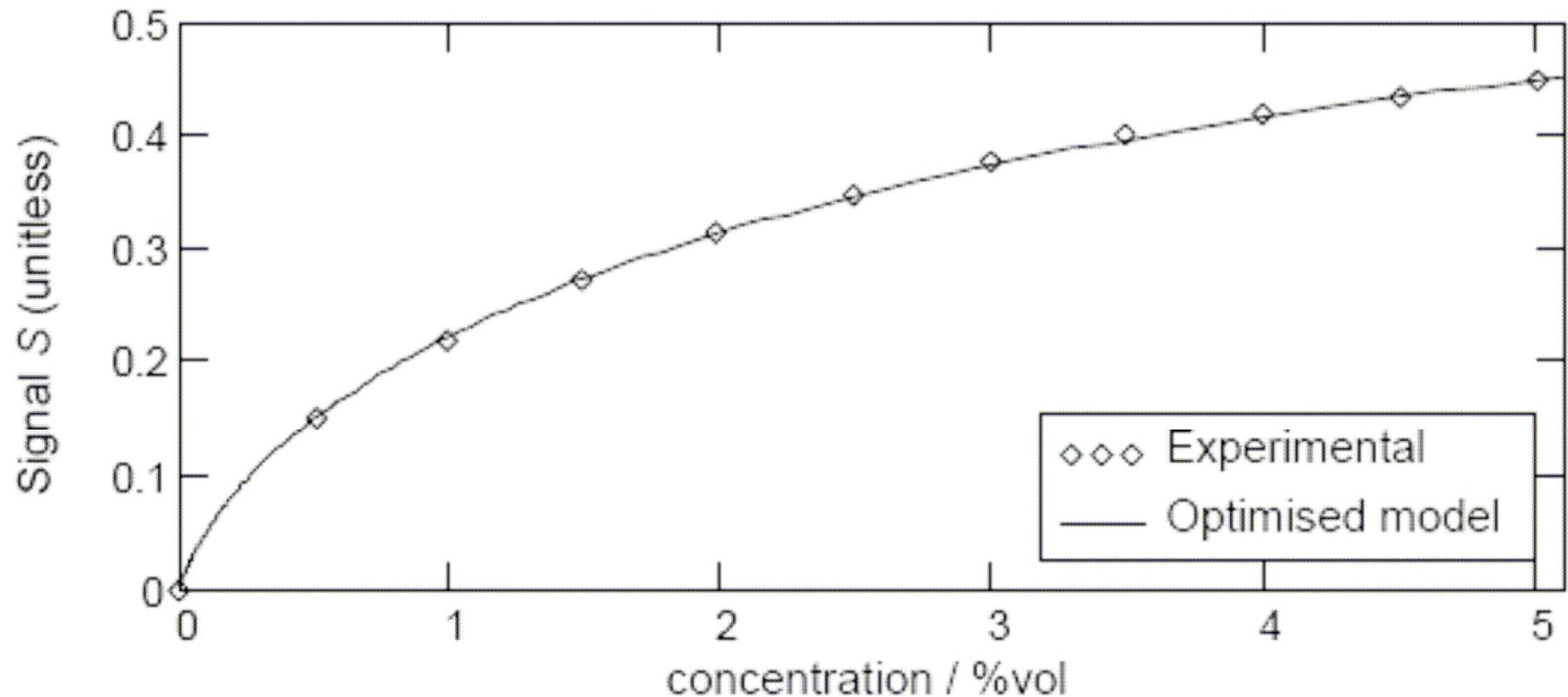
Notch filters have different centre frequencies and widths. This affects the amount of non-absorbing light on the detector.  
**Below are two detector filters we use**



Filter bandwidth affects the signal Beer-Lambert linearity because of the non-absorbing radiation.



Good agreement when experimentally fitted with “top hat” filter with centre wavelength of 4.23um and fwhm of 0.274um.



# Problems of pathlength

Beer Lambert Law assumes one pathlength. This is not achievable in a small optical system:

- The finite dimensions of the source (tungsten coil) spread the pathlength.
- Optical geometry controls pathlength distribution:
  - scattering between two plates (integrating sphere-almost)
  - simple waveguide
  - focused parabola/ mirror (our design)

# Model the optics with Zeemax:

ZEMAX-EE - 8 - C:\Program Files\Zemax\Samples\Non-sequential\Alphasense\pathlength distribution\Bulb in hole (p3) for export, PYS3228.ZMX

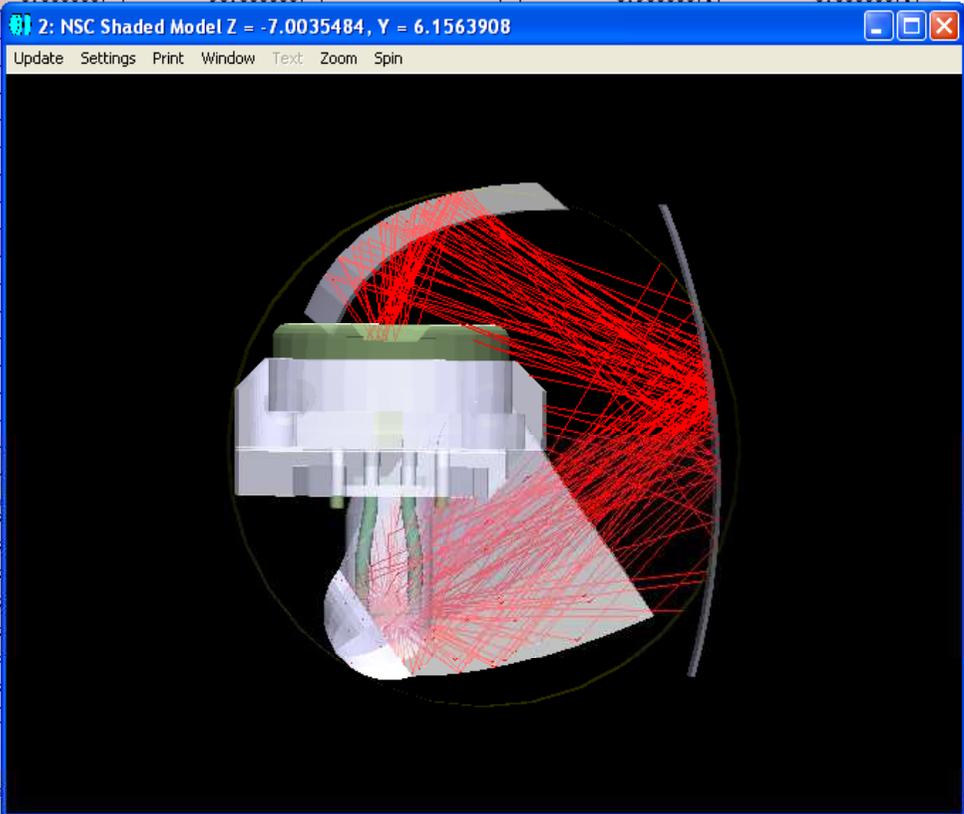
Non-Sequential Component Editor

Edit Solves Errors Detectors Database Tools View Help

Object Type	Tilt About X	Tilt About Y	Tilt About Z	Material	# Layout Rays	# Analysis Rays	P
1 Null Object	0.000000	0.000000	0.000000	-			
2 Detector Rect	90.000000	0.000000	90.000000		1.500000	3.500000	
3 Detector Rect	90.000000	0.000000	90.000000		0.900000	0.800000	
4 Detector Rect	90.000000	0.000000	90.000000		0.900000	0.800000	P
5 Detector Rect	90.000000						
6 Biconic Surf..	40.000000						
7 Null Object	0.000000						
8 Null Object	0.000000						
9 CPC	-35.000000						
10 Ellipse	40.000000	P					
11 Imported	0.000000						
12 Imported	90.000000						
13 Source Filam..	0.000000						
14 Imported	-90.000000						
15 Standard Sur..	0.000000						
16 Biconic Surf..	-4.000000						
17 Standard Sur..	0.000000						
18 Cylinder Pipe	0.000000						
19 Standard Sur..	0.000000						
20 Standard Sur..	0.000000						
21 Imported	-90.000000						

2: NSC Shaded Model Z = -7.0035484, Y = 6.1563908

Update Settings Print Window Text Zoom Spin



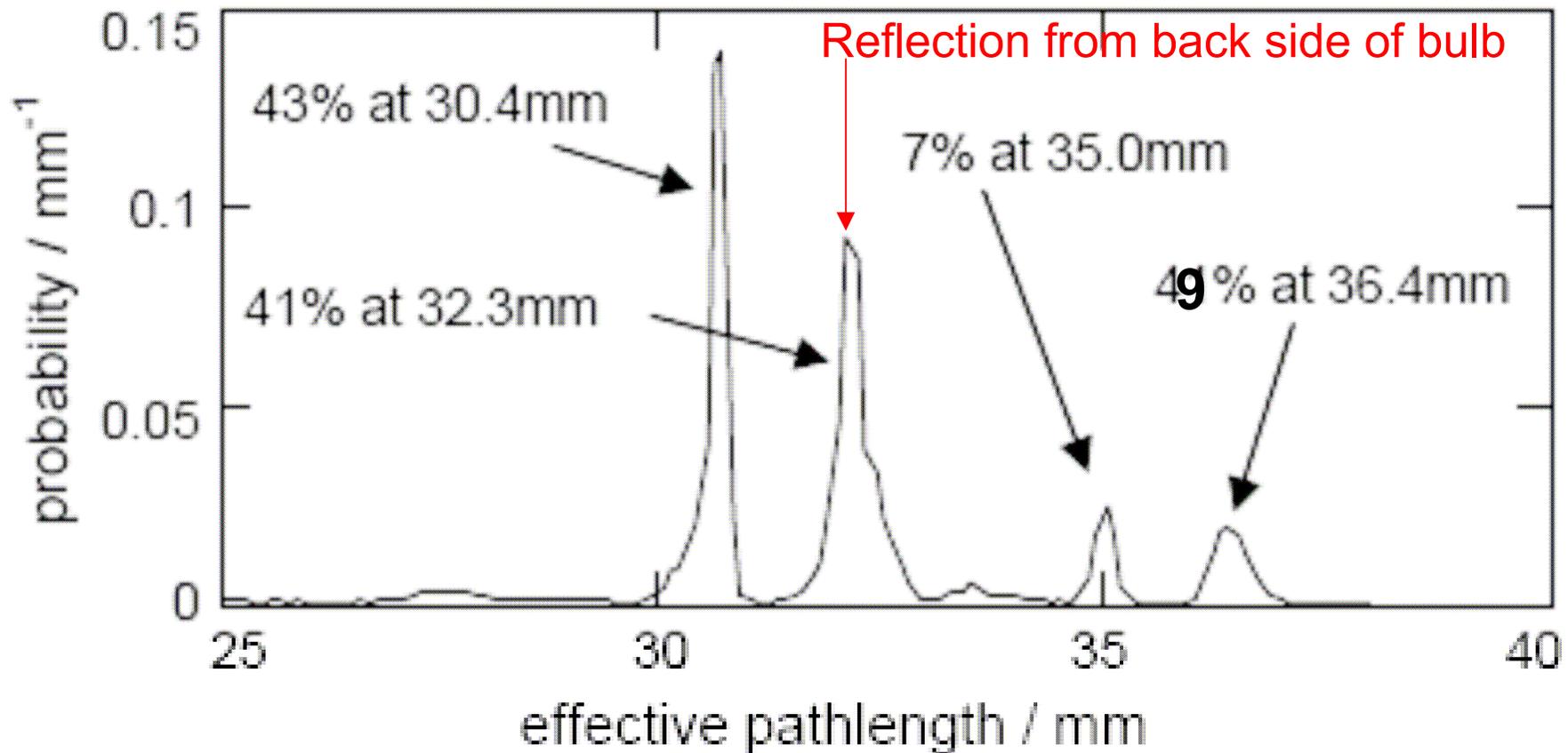
DETECTOR IMAGE: INCOHERENT IRRADIANCE

WED MAY 20 2009  
DETECTOR 6, NSC SURFACE 11, DIMMY 4  
SIZE 1.000 U X 1.000 H MILLIMETERS, PIXELS 96 U X 96 H, TOTAL HITS = 0  
PEAK IRRADIANCE = 0.000E+000 HITS/CM^2

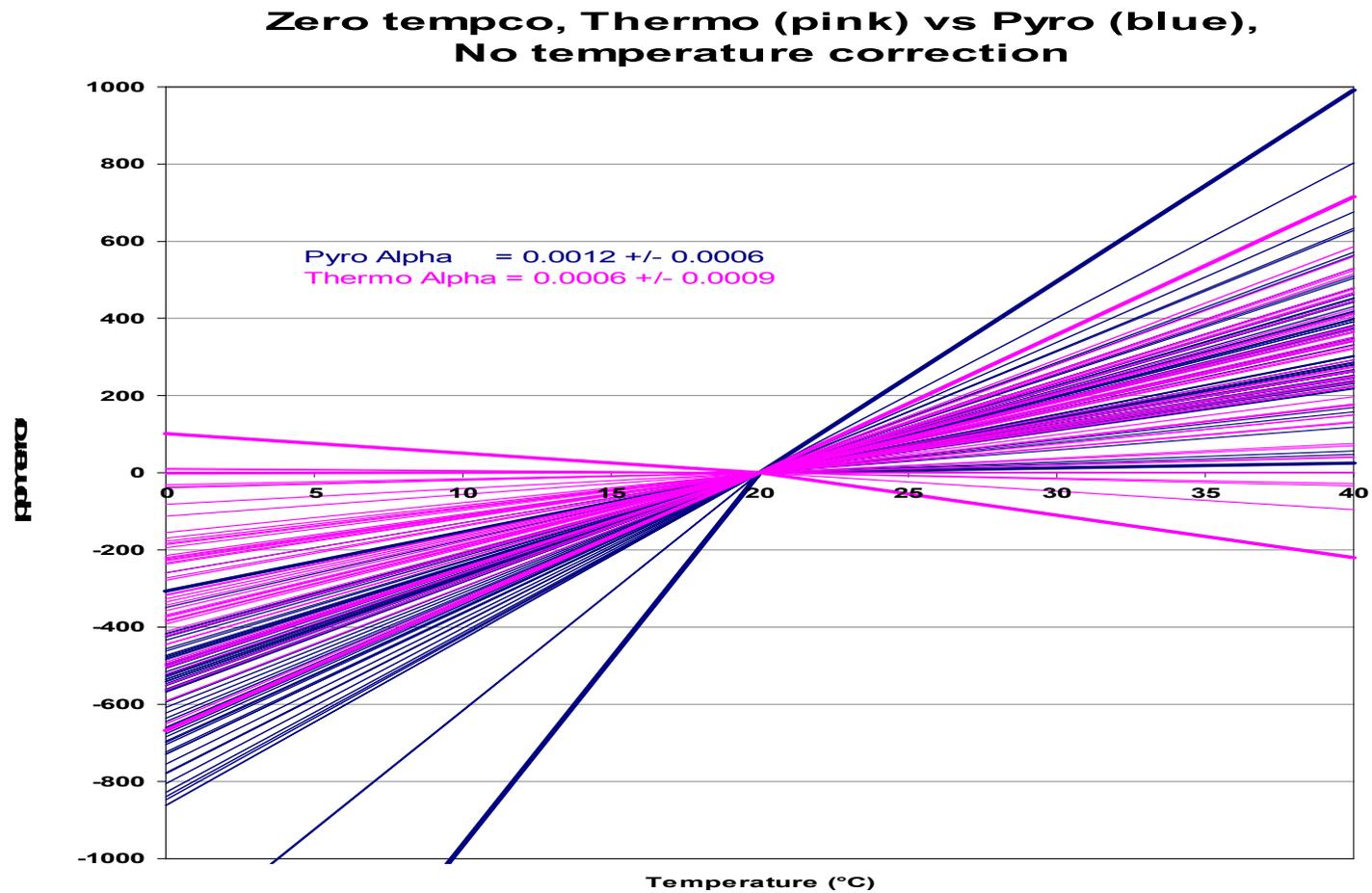
7: Ray ...

start | Inbox - Microsoft Out... | recruitment | ZEMAX-EE - 8 - C:\Pr... | EN | Google | 10:53

# Determine the probability distribution function of effective pathlength

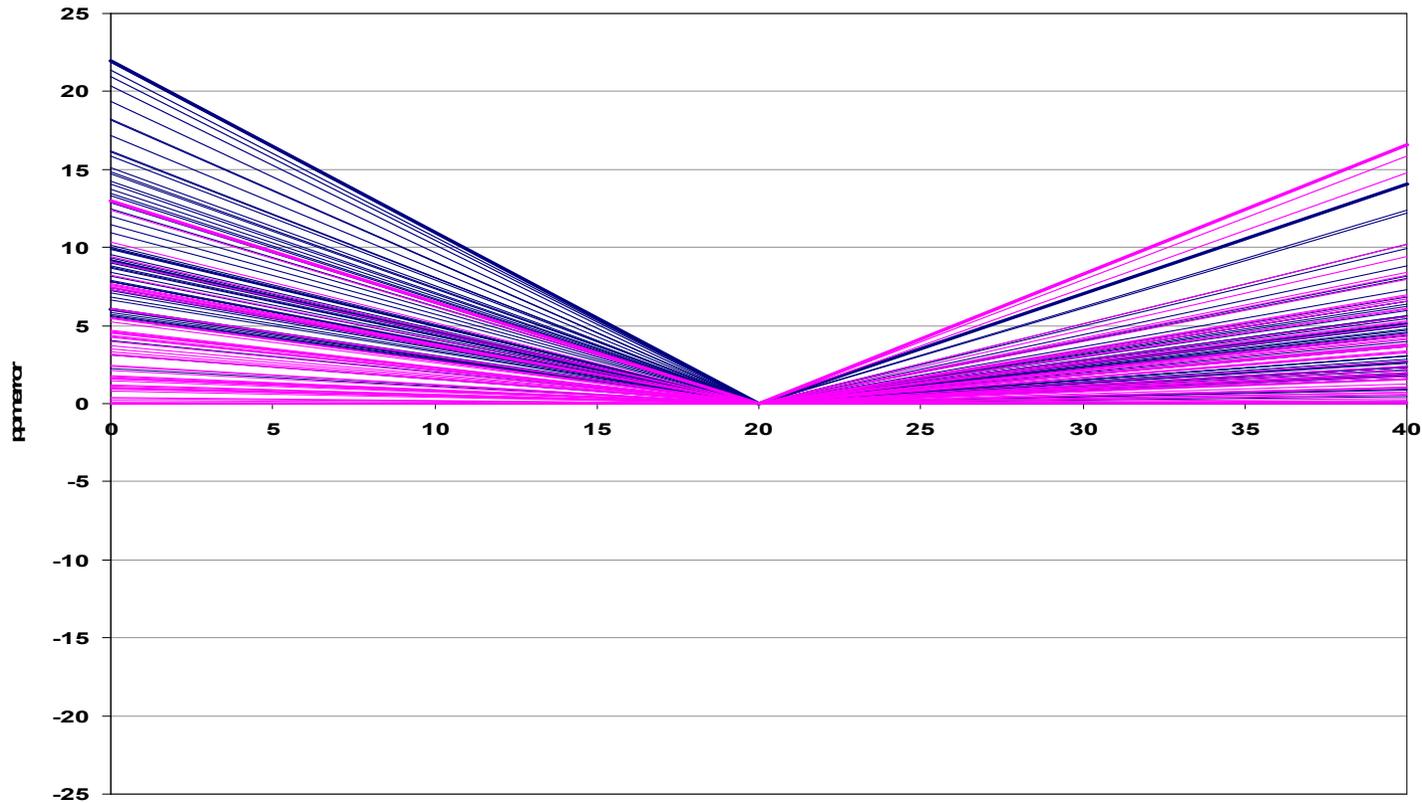


# Detector zeros shift with temperature



# A universal linear spline fit corrects zero to an acceptable error

**Zero tempco, thermo (pink) vs Pyro (blue),  
Spline temperature correction  
(note 40x reduction in error scale)**



# Conclusions

- Beer Lambert Law assumes monochromatic light with a single pathlength.
- NDIR cells have a distribution of pathlengths and measure over a band of wavelengths.
- Detector filters play a crucial role in performance because of filter bandwidth and field of view (FOV) errors.
- Careful optical path design minimises FOV and pathlength distribution errors.
- Lower concentrations follow Beer Lambert closest because of reduced analyte shadowing.
- As the cell approaches Beer Lambert performance, the cell can use universal calibration constants with little error.

# Acknowledgements

- Wah On Ho
- Ralph Tatam
- Jane Hodgkinson
- Riyadh Zachariah
- Alan Doncaster

Alphasense Ltd.

Cranfield University

Cranfield University

Cranfield University

Clairair Ltd.

